

Measurement of Thermal Effects on the Advanced Photon Source Storage Ring Vacuum Chamber

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Abstract

From the start of operations of the Advanced Photon Source storage ring, we have observed small thermally related dipole sources appearing soon after filling. Because there are many like sources occurring at about the same time, it has been difficult to locate them. Some sources have recently been located with a specially configured orbit correction running while the vacuum chamber temperature is changed. Vacuum chamber motion, seen as an apparent orbit change, can also be estimated from the results

Keywords: orbit stability, thermal stability

1. Introduction

The thermal effects on the closed orbit and beam position monitor (BPM) readbacks at the Advanced Photon Source storage ring (SR) are subtle. One has to distinguish between a real orbit displacement and a widespread displacement of the BPMs, which move with the vacuum chamber. Depending on the type of thermal disturbance, one type of displacement or the other may be present, and sometimes both. If the BPM readback change is caused by a real orbit displacement, allowing orbit correction to reduce the displacement is the right thing to do, although it would be good to eventually identify and correct the source. If the BPM readback change is due to a widespread displacement of the vacuum chambers, it may appear like a normal orbit displacement, but allowing orbit correction to reduce the BPM readback is the wrong thing to do, and causes a real steering of the stored beam. The orbit and BPM displacements that occur during operations are small (and easily correctable for the former), but have a significant impact on the user steering because the effects are measured on the scale of a low-emittance beam.

We observe three thermal disturbances during user operations. The first one is related to filling the ring to 100 mA. Heating of unknown parts occurs, which causes a significant real orbit displacement and minor BPM displacement. The presence of closed-orbit sources are evident by the way orbit correction behaves to keep the closed orbit small.

The second thermal disturbance is a change in temperature of the water cooling the aluminum extrusion vacuum chamber. The change in temperature deforms the vacuum chamber slightly and displaces the position of the BPM buttons. For the 40 sectors of the ring, there are 20 separate closed-loop stations for the cooling water. The temperature regulation is quite good ($<0.1^\circ\text{F}$), but occasionally, in the past, a 1°F 20- to 30-min oscillation occurred in one of the stations and affected a few user's beamlines.

We previously believed that a deformed chamber was the only consequence of a temperature variation, but the analysis presented here shows that a real orbit disturbance is also associated with the temperature variation. This finding is unexpected because there is supposedly no direct contact between the vacuum chambers and the magnets, which are the only plausible source of orbit displacement.

The third thermal disturbance is a change in air temperature in the tunnel. Occasionally, one of the 20 air handler systems fails to regulate and produces either a one-time temperature step of several degrees or a temperature oscillation. We believe that the affected accelerator components are the magnets but not the vacuum chambers because the vacuum chambers' temperatures are tightly regulated by cooling water. The quadrupole magnets have an ~ 2 -cm-thick vertical aluminum spacer plate on the sides for holding up the top core of the magnet. A temperature change might cause lifting of the top two poles by a few microns, effectively creating a displacement of one-half the expansion length, though the effect on the beam is partially offset by the neighboring quadrupoles of opposite polarity.

The above thermal perturbations on the beam and on the BPM displacement have been characterized by passive observations. Various observations will be reported, then a water temperature experiment will be described that amplifies the scale of the effects under study.

2. Passive Observations

When the ring is filled to 100 mA, we observe a closed-orbit distortion settling with a time constant of about 3.5 min, and that the vacuum chamber heats up a bit. The closed orbit grows to 80 μm in the horizontal plane (orbit correction not running) after a rapid fill from 0 mA to 100 mA. The orbit growth in the vertical plane is much less, about 20 μm . When orbit correction is on, all correctors involved react about equally (median absolute value of 0.4 μrad) to the presence of beam, which seems to indicate that orbit sources are everywhere.

To make general investigations on vacuum chamber heating, one vacuum chamber (sector 25 girder 5) was instrumented with three sets of eight resistance temperature detectors (RTDs) placed along the contour of the extrusion. There are RTDs on the beam chamber, the pumping slot, and the antechamber. The sets are longitudinally separated along the vacuum chamber, forming a 3-by-8 matrix of RTDs. The RTD readbacks have a resolution of 0.06 $^{\circ}\text{C}$, but heavy averaging can improve the resolution of long-term temperature readings. Figure 1 shows a clear RTD signal of 0.2 $^{\circ}\text{C}$ when beam is dumped or when beam is injected. A linear dependence with current of the same magnitude was seen another time when the ring was filled to 100 mA slowly over a period of 48 h. The group of RTDs in the figure are located on the upper part of the beam chamber where some synchrotron radiation power from very low-energy photons may be striking the outboard side of the beam chamber. We expect the same type of temperature effect on the other chambers. The temperature increase of 0.2 $^{\circ}\text{C}$ appears to be a minor effect.

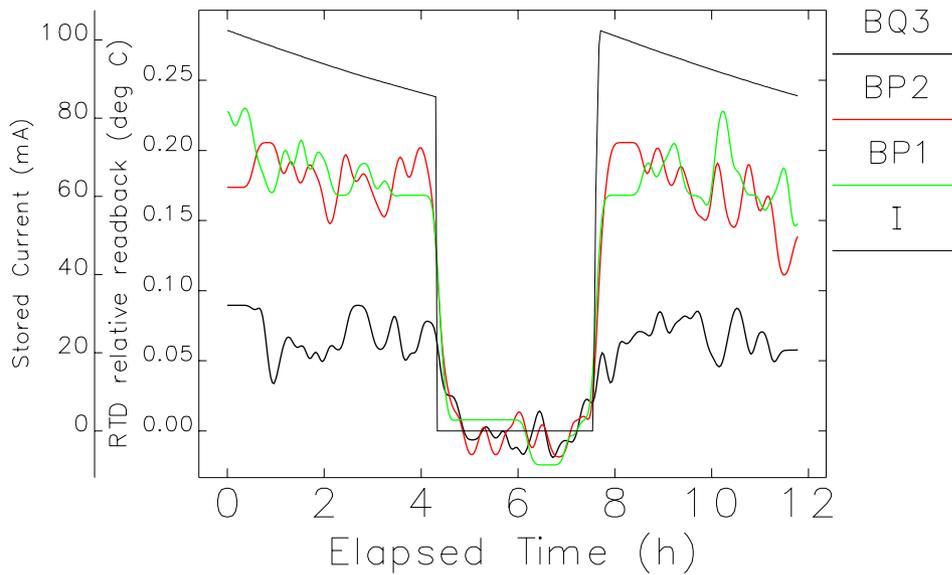


Fig. 1: RTD relative readback dependence on stored beam. BQ3, BP2, and BP1 are along the beam direction.

Another observation was the correlation between a 22-min oscillation in water temperature from one faulty controller and the oscillations in the readbacks of 18 BPMs in the sectors that the water system controlled. The oscillation amplitude was known to be 1 °F. With or without orbit correction, each BPM readback would oscillate at its own constant amplitude for the duration of the water temperature problem, which lasted for a month in 1999. The largest amplitude was $\pm 6 \mu\text{m}$ in the horizontal plane and $\pm 6 \mu\text{m}$ in the vertical plane with or without orbit correction. The orbit correction effort was about $\pm 0.6 \mu\text{rad}$ for the neighboring magnets, but was ineffective in reducing the orbit error in the sector because the BPM readbacks were not representing a real orbit.

The last observation of thermal perturbation is that of air temperature glitches. The air temperature is expected to displace many magnets in the general area and cause an orbit displacement that is corrected almost immediately by orbit correction. We have installed several RTDs at critical points in alternate sectors: magnet spacer plates, vacuum chamber, ambient air, and return air duct. Figure 2 shows a typical air temperature glitch and the corrector response to the orbit error.

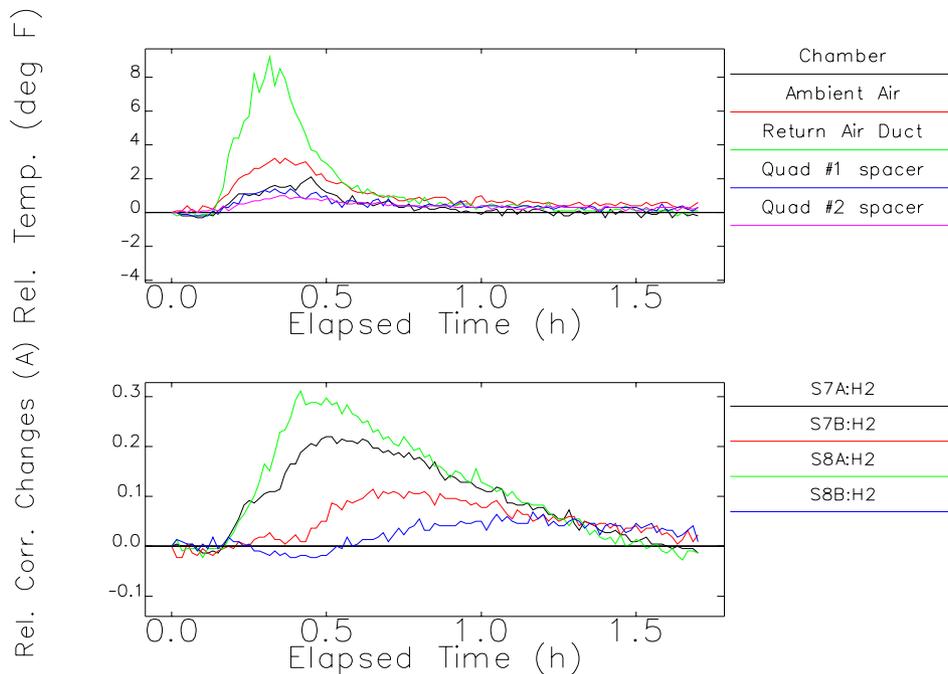


Fig.2: A group of correctors responding to a local air temperature glitch.

The largest temperature change is usually seen at the return air duct. The relevant temperature is that of the magnet spacer plate because, we suspect, the source develops there. Two magnets 20 m apart show the same 1.5 °F change. Presumably, other magnets in the area were affected the same way. A response came from the four correctors used in the two sectors in each plane.

The angle of the correctors is equivalent to a quadrupole motion in both directions by 4 μ rad, which agrees roughly with the effect of expansion of the quadrupole spacer plates of about 2 μ rad for a 1.5 °F change. Because the expansion of a quadrupole is expected to produce only a vertical orbit displacement, the horizontal motion is unexplained.

3. Experiments

The temperature of the vacuum chamber is tightly regulated by the cooling water, and we therefore expected a minimal distortion as a result of the presence of beam. However, the above observations contradict this expectation. To gain some knowledge of the system, we measured the displacement of some BPMs and the beam displacement for a large temperature change. The experiments were simple: change the setpoint of one or more temperature controllers and collect all the relevant data.

It was important to create a large and rapid temperature change to avoid interference from other effects. The temperature variation was the same for all experiments: a drop of 10 °F, and regulating at the lower temperature until an equilibrium is reached.

We measured the displacement of three BPMs with a LEICA LT-300 laser tracker system, which has a built-in interferometer. One BPM was selected from the vacuum chamber equipped with the 24 RTDs so that the BPM position and the temperature of the chamber could be correlated. The other two BPMs were selected from the dipole curved chamber, where experience showed that the largest temperature-dependent offset was expected. We could examine only a few BPMs because only one at a time can be measured.

Figure 3 shows the relatively rapid response of the water system and the transient values of the BPM displacements, which imply a deformation of the chamber during the transition. After a new equilibrium is reached, the BPM displacement is less, but still significant.

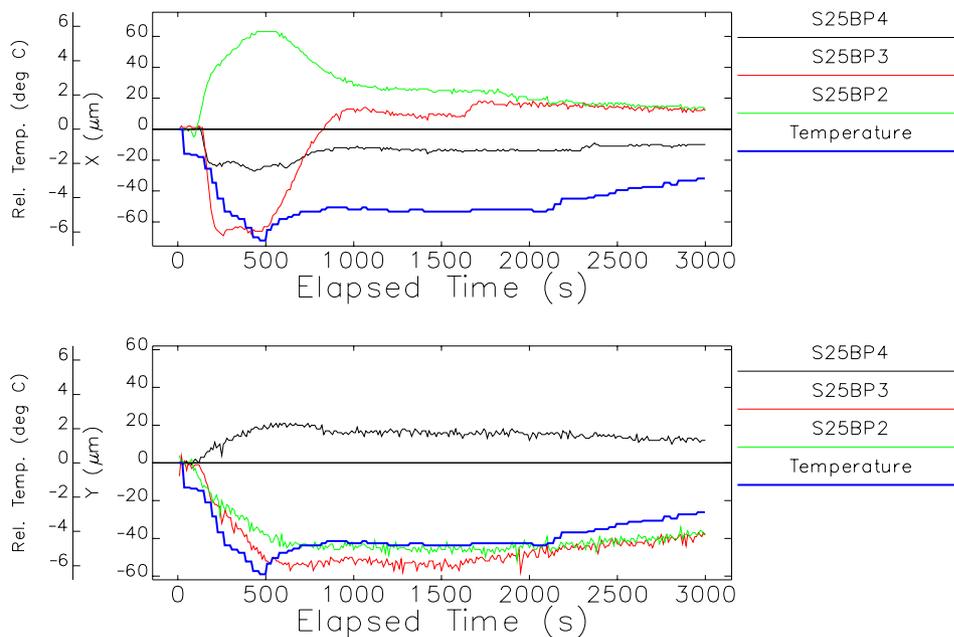


Fig 3: Displacements of three consecutive BPMs caused by a temperature change in the vacuum chamber.

This large signal allows us to make a more accurate specification of the required tolerance for temperature control of the vacuum chambers. Because temperatures are expected to move slowly in normal operations, we use the maximum equilibrium values of $5 \mu\text{m}/^\circ\text{F}$, which would indicate a tolerance of $0.2 \text{ }^\circ\text{F}$ for a $1\text{-}\mu\text{m}$ beam stability.

The individual control of the water systems gives us the opportunity to investigate the dipole sources within a two-sector zone. For the sector pair selected for a temperature change, we create a special orbit correction configuration that allows all BPM errors in the zone to be free and excludes all correcting elements from the zone. The correctors adjacent to the zone act to automatically “close” any perturbation generated inside. The data collected are the corrector setpoint changes caused by orbit

correction and the BPM readbacks inside the zone. The experiment can be parallelized easily to measure the effects of ten unconnected pairs of sectors at a time.

Using the corrector setpoint data, the program `elegant` [1] was used to fit the displacements of a particular quadrupole in each sector as two unknown dipole sources inside the zone. The fitting is repeated for all time steps. The tracking program indicates that fitting the displacements at other girders in the horizontal plane gives very poor agreement. The horizontal plane results are particularly striking because the tracking predicts very closely the BPMs data in most sectors.

Figure 4 shows a snapshot of the BPM readbacks and the predicted horizontal orbit for the sector 25 experiment when the BPM readbacks peaked. This sector is shown because we have data for the BPM displacement from the laser tracker. There are discrepancies for the large negative readbacks, but when the contributions from the BPM displacements are included (see Figure 3 at the peaks), the fitted orbit and the readbacks agree much better (not shown). Note that the orbit correction did not use information from the BPMs in the two-sector zone; the correctors responded only to keep the orbit error small outside the zone.

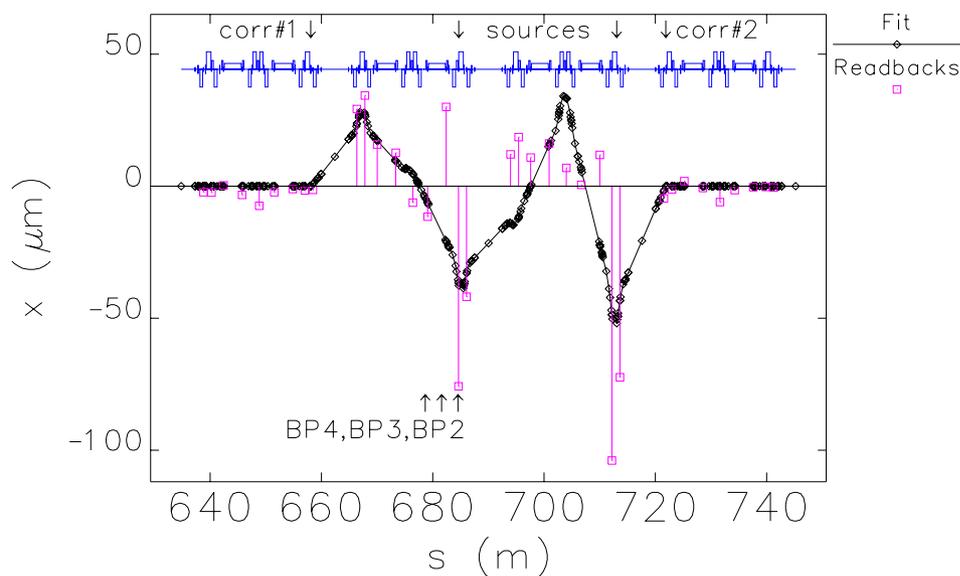


Fig. 4: The BPM readbacks and predicted orbit in a two-sector zone where orbit perturbations from temperature have been localized. Indicated BPMs are those whose displacement were measured with a laser tracker.

The correctors of the vertical plane show far fewer orbit sources, and the BPMs show the same pattern in both sectors — suggesting that the BPM readbacks are mostly displacements.

We can draw many conclusions from this experiment. The sources appear to be located in the downstream triplet girder for all sectors (though not necessarily at the quadrupole used for fitting). The perturbation strengths are about equal in all sectors. The BPM displacements caused by temperature can be estimated by the differences seen in the predicted orbit and the BPM readbacks. This assumes that there are no sources elsewhere in the sector. Views of other sectors show that the displacements are sometimes large and sometimes practically nonexistent.

The thermal effects seen in the experiments are scaled up 100 times compared with what is expected in the ring from water temperature regulation. The thermal effect due to the presence of beam may not necessarily produce the same dipole source and BPM displacement as the water temperature experiment. However, the observed widespread occurrence of both processes suggests that they are related.

4. Acknowledgments

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5. References

- [1] M. Borland, APS Light Source Note LS-287, (September 2000). See URL <http://www.aps.anl.gov/techpub/lnotes/lnotesTOC.html>.